CHEMSYSTEMS®
PROSPECTUS

Bio-Based Chemicals:

Going Commercial

Nexant

CHEMSYSTEMS®

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Going Commercial

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CHEMSYSTEMS – a brand owned by Nexant, Inc. that provides support to decision makers in the petroleum, chemical and petrochemical industries

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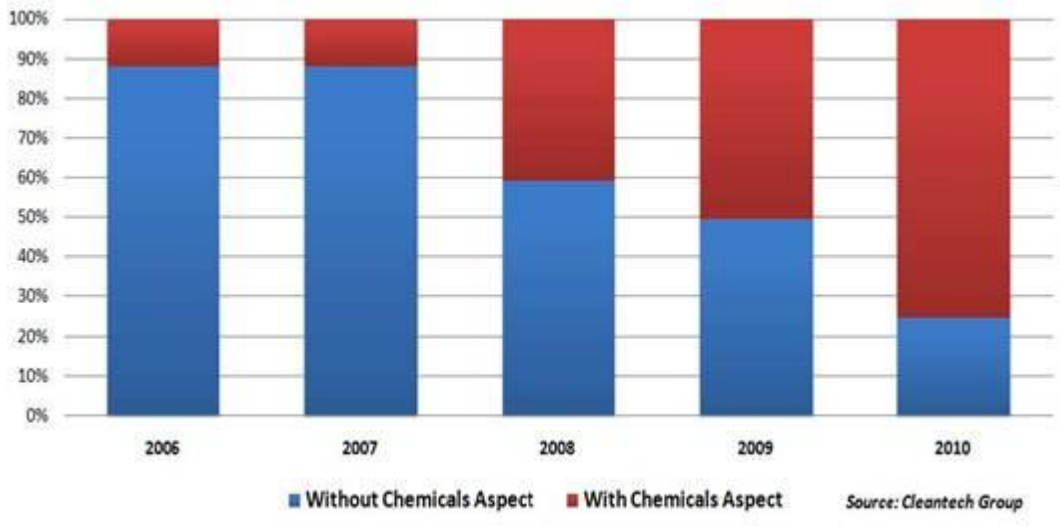
Responding to economic and market drivers, some of the world's largest chemical producers are pursuing projects to more profitably manufacture chemicals along with or instead of biofuels. This is taking place during a period of uncertainty as many governments reconsider carbon regulation, biofuels subsidization, and biofuels development funding, and as biofuels developments hit numerous other practical and political obstacles. At the same time, oil prices have been consistently at or above $100 per barrel. All fuels prices ultimately are tied to crude oil indexes, but some basic chemical value chains are related more to natural gas price dynamics, which are increasingly being influenced by development of shale gas and its associated gas condensates. Chemicals further down the value chain are more independent of underlying fuel prices and are more value-priced.

Figure 1.1 illustrates how investor's interest in bio-companies having renewable chemicals aspects has grown.

Figure 1.1 Share of VC Investments in Biofuels Companies
(With/without renewable chemicals aspects)



Some bio-based commodity chemicals, (i.e., ethylene from ethanol, bio-butanol, and citric acid) have long been commercial. However, the new environment has created an exciting tipping point in strategic partnering, investment, and construction that is driving rapid growth in renewable chemicals commercialization.

Many new projects are being announced by biotech process developers allied with credible conventional industry players. Public offerings of stock (IPOs) are being promulgated at a rapid pace, rivaling the dot-com phenomenon. Developing projects cover a wide range of end-uses, from commodity thermoplastic, thermoset and specialty polymers, to solvents, surfactants, lubricants, coatings, plasticizers, other additives, fragrances, emollients, and nutraceuticals. Projected growth rates for renewable chemicals are significantly above conventionally-sourced chemicals, and thus the high industry interest.

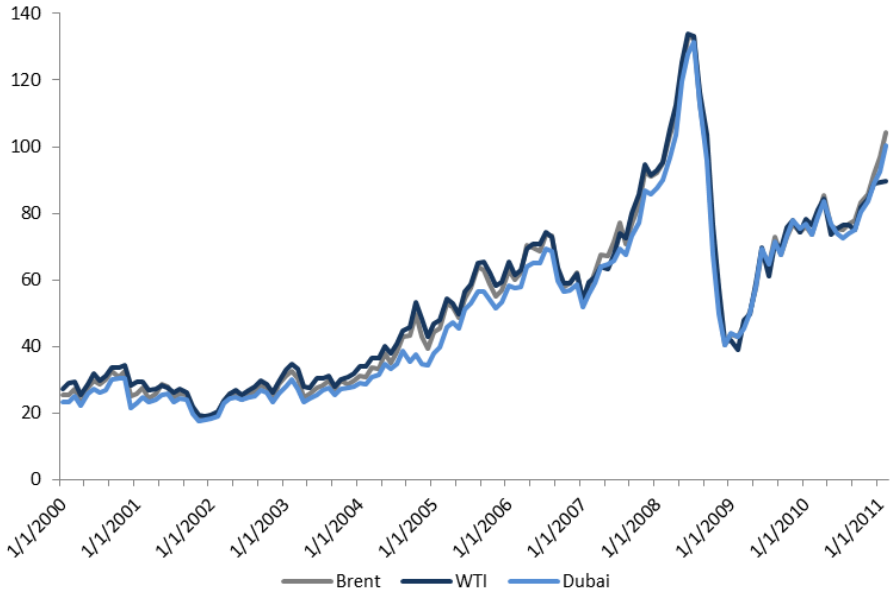
What are the implications and issues around these developments? How will they disrupt and/or benefit industry and impact society and sectors upstream and downstream? How do identical renewable replacements (e.g., renewable ethylene is the same molecule as conventionally-produced ethylene) differ from different renewable molecular replacements, such as PLA and PHAs (i.e., Metabolix's Mirel™ polymer line)? What is the current size and real growth rate of this sector? How reliable are various capacity announcements? How well financed are the companies and their projects? How sound are their business plans?

This report creates a more accurate index of current progress and a more nuanced and better grounded view of future potential in renewable chemicals commercialization than has previously been available.

1.1 DRIVERS

The most significant driver of renewable chemicals commercialization is the high and apparently rising price of crude oil. Figure 1.2 shows the recent history of global crude oil prices in terms of three benchmark prices from sources in the United States (WTI), Europe (Brent), and the Middle East (Dubai). These prices went from a relatively stable long-term plateau ranging between $30 and $40 per barrel, to a peak of around $140 per barrel before the economic crisis of 2008 to 2009, during which they rapidly fell to just over $40 per barrel. With the recent political crises in the Middle East and vibrant economic growth in Asia and other developing regions, prices are ramping up again at rates similar to the period before the crisis. Oil prices over $100 per barrel are considered by many experts to be the "new normal" for the longer term.

Figure 1.2 Global Crude Oil Prices
(Dollars per Barrel)



This trend has instilled fear among chemical producers and end users that the future could hold the reality of a high oil scenario maintained at levels never seen before for an extended period.

Nexant believes that biofuels and renewable chemicals can be competitive with petroleum fuels and petrochemical products under these conditions.

While Nexant also believes that renewable chemicals will not displace significant fractions of conventional chemicals market volumes unless their prices are fully competitive, there are other drivers for their adoption that can work hand-in-hand with competitive economics. Other important drivers include:

- Green marketing initiatives and competition among brands, such as for mass market food and beverage packaging, and durable goods such as automobiles, furniture, and clothing
- Individual consumer preferences for renewably-sourced products
- Purchasing mandates by national, regional, and local governments, either in a manufacturer's country, or for export goods
- Reduced toxic pollution from manufacturing that can help with producers' environmental regulatory compliance
- Local, regional, and national carbon trading or other clean manufacturing credit trading
- Breakthroughs in the routes available, economics, scale of, and experience with bio-renewables chemicals production and use, which increase the options for renewable chemicals production, and decreases the technical and business risks of their adoption.

There has been significant push-back against biofuels and renewable chemicals based on a perception of competition between bio-renewables and human food and animal feed production. This "food versus fuel" debate has thwarted the development of renewable chemicals somewhat, but not as much as for biofuels. Perhaps this different public perception is because biofuels are more heavily subsidized by public funds and mandated in public policy than renewable chemicals, whose advent is more driven by consumer demand and economics than public policy or subsidization. In addition, the scale of operation for bio-based chemicals generally is significantly smaller than for biofuels.

As we get closer to a model of producing and feeding biomass-derived sugars to fermentation, and/or successful implementation of thermochemical routes exploiting biomass, and/or hybrid routes combining gasification or pyrolysis with secondary fermentation steps, the flexibility of the technologies and their utilization of different feedstocks are further improved. As this moves forward, the food versus fuel debate will quickly be obviated.

1.2 TYPES OF RENEWABLE CHEMICALS CONSIDERED

There are a number of different types of renewable chemicals that were considered in this report:

- **Bio-sourced identical replacements** for molecules that are conventionally made from fossil sources, including certain alcohols, organic acids, and even some hydrocarbons. Examples are (industrial) ethanol, *n*-butanol, iso-butanol, fumaric acid, acetic acid, succinic acid, and isoprene made in fermentations or BTX extracted from biomass thermochemical processing. These can be thought of as "drop-in" replacements that generally do not need much certification if they meet quality specifications.
- **New types of renewable chemicals** that were not previously industrial products made from fossil resources, such as lactic acid made by sugar fermentation and intended for PLA manufacture, or PHAs and PHBs, whether made by fermentation or extracted from genetically modified crops. These generally are not "drop-in" since they are functionally different (e.g., biodegradable versus non-biodegradable).
- **Functional replacements in kind** – different molecules than conventional that provide the same or similar functions in end use products, often oxygenates substituting for hydrocarbons, such as ethyl lactate substituting for hydrocarbon or halocarbon solvents. Note that for fuel applications, which are generally more flexible, as long they work in engines and distribution systems, can be considered drop-ins, such as isobutanol for gasoline.
- **Renewably produced identical replacements for first step, or "platform" molecules** in conventional chemical value chains, which are mostly hydrocarbons, such as ethylene made from ethanol, isobutylene made from bio-isobutanol (there is also a fermentation route being developed for the direct production of isobutylene).

1.3 TYPES OF COMMERCIAL DEVELOPMENTS CONSIDERED

This report emphasized inventorying and analyzing the reported commercial progress in producing any of these types of renewable chemicals, but not the downstream derivatives. Thus, we count the capacity and product value of projects to make ethylene, but not polyethylene (PE) derived from it, since the PE could be manufactured in existing or new facilities and presents nothing new in itself. The consideration of the bio-ethylene only is sufficient to serve as an incremental measure of bio-renewable chemicals' penetration of the chemicals sector and any consideration of derivative volumes would confuse the inventory by multiple-counting.

The approach of this study can be understood by the example of Figure 1.3, which shows part of a particular value chain for chemicals production, including two alternative routes to BDO (1,4-butanediol). BDO has a global production of around 34 billion pounds per year, valued at $3 billion. BDO has end uses in spandex, urethanes for running shoes, automotive components, etc. While the Genomatica-Tate and Lyle partnership is pursuing a direct route, the main route to BDO through succinic acid is being pursued by multiple coalitions. Succinic acid, a four carbon dicarboxylic acid, has uses in a number of industries including polymers (textile fibers), food, surfactants and detergents, flavors and fragrances, and as a starting material for a number of chemicals besides BDO, including adipic acid, N-methylpyrrolidone, 2-pyrrolidone, succinate

salts, maleic anhydride, tetrahydrofuran and gamma-butyrolactone. **The production of bio-succinic acid and direct bio-BDO are considered for the report's inventory, which also considers new capacity for production of bio-BDO from bio-succinic acid.** Other derivatives of succinic acid are not considered, nor are derivatives of BDO, since they are already made from the fungible petrochemical version of BDO.

Figure 1.3 BDO – Succinic Acid Value Chains

(Everything shown is counted in the inventory)

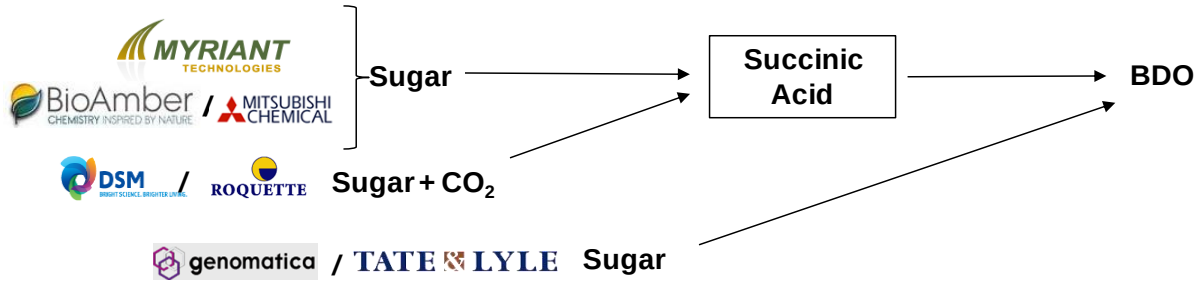
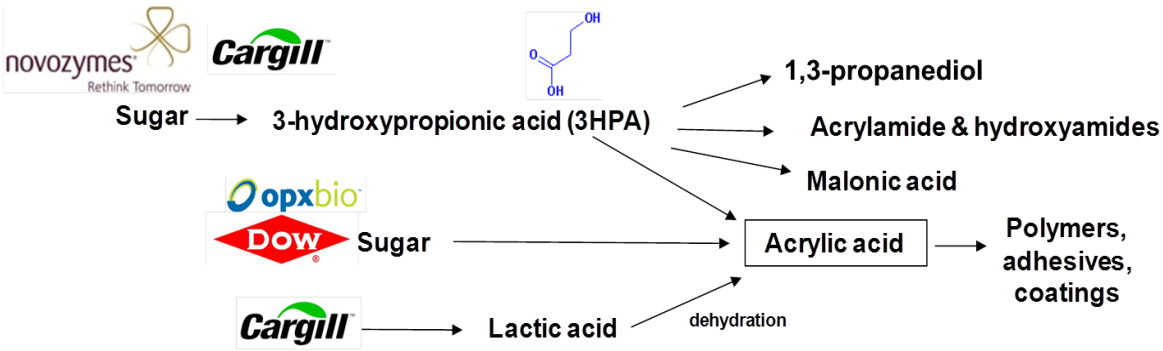


Figure 1.4 gives another value chain example - that of making bio-acrylic acid. The routes considered are:

- Directly from sugar
- Through dehydration of lactic acid
- Through 3-hydroxyproprionic acid (3-HPA) (with other potential derivatives)

Each one of these new routes and bio-based derivatives, but not the acrylic acid derivatives, are considered for inventorying in the report. The distinction is fungibility – the production of "green" derivatives from bio-acrylic acid is identical to that for petrochemical acrylic acid.

Figure 1.4 Acrylic Acid and 3-HPA Value Chains



There are many similar competitive renewables based chemical value chains in the industry. These involve a broad slate of biotech companies and conventional industry partners, that are numerous and varied. Feedstock and biomass suppliers are also heavily engaged.

Also considered is commercialization of technologies to convert biomass to usable sugars or by anaerobic digestion to biogas (methane and CO_2) and for biomass gasification, for either of the latter to produce syngas. These initiatives may be currently embodied in projects to produce biofuels, but they are included because they can eventually be used to feed renewable chemicals processes.

Nexant maintains in-house databases and monitors public sources regarding renewable chemicals to structure this inventory ("top down" analysis), but also examines the progress in making chemicals on a list of feasible candidates ("bottom up" analysis). For example, Nexant has considered progress in the following renewable chemicals/routes among others:

- Acrylic acid
- Adipic acid
- Acetic acid
- Alpha olefins ex oils
- BTX
- Lactic acid/PLA
- Butadiene
- 1,4-BDO
- *n*-Butanol
- *iso*-Butylene
- Isoprenoids
- Renewable lube base oils, waxes, hydraulic –fluids
- PTA (*p*-xylene routes)
- Ethylene
- Propylene
- Succinic acid
- Bio-ammonia
- Bio-methanol and Bio-DME
- *iso*-Butanol
- Others

The report distinguishes the chemicals production of "biorefineries" from their fuels production. Thus, if a facility making higher alcohols extracts propanol as a byproduct and sells the rest for fuel, only the propanol production is counted as chemicals production. A number of developers aim to make propanol for dehydration to bio-propylene. If byproducts enter the chemicals value chain, such as green glycerine from FAME biodiesel, or green propane from hydrotreating oils to produce renewable diesel, these are counted. In many cases, sales of higher-priced chemical byproducts or co-products will help biofuels manufacturers get needed initial revenues before they achieve larger scale production of fuels. An example is *n*-butanol or isobutanol by fermentation, where these alcohols sold into chemical markets will command prices several times greater prices than as fuels (gasoline blending, biodiesel, or jet).

The objective of this report was to create a more accurate index of current progress in renewable chemicals commercialization and a more nuanced and better-grounded view of future potential than is currently available.

The types of bio-based chemicals profiled are:

- **Alcohols –** [only as dedicated to the next step in a chemicals value chains, (e.g., to olefins, esters, etc., not fuels)] by fermentation, thermochemical, or photosynthetic algae routes, the latter such as by Algenol
- **Acids** - including acetic, acrylic, succinic, adipic, levulinic, lactic, citric, ascorbic, dicarboxylic acids, etc., generally by fermentation
- **Algae oils** - (by heterotrophic systems, such as by Solazyme and Martek, or phototrophic systems, such as by most other developers) for oleochemicals, other specialties, LAOs, etc., but not for foods or nutraceuticals
- **Isoprenoids** – [Amyris, Genencor (isoprene), etc.]
- **Aromatics -** including extracted from biogasoline made by Primus, or by the aqueous catalytic route of Virent
- **Olefins** - (by direct routes, such as Global BioEnergies' bio-isobutylene, etc.)
- **Others** - (not classified above)

Chemicals that are derived from these were considered for inclusion based on their manufacturer's departure from conventional routes. Thus, chemicals derived from bio-based materials in the identical manner as petrochemical feeds are not included.

For the chemicals considered, Nexant identified and catalogued announcements of new capacity additions with respect to the following information, as available:

- Name of the chemical
- Owner, developer of the facility, source of finance, additional sponsorship
- Location – city/town, state, province, country
- Capacity in tons per year
- Announced construction, startup schedule
- Feedstock, type of process (fermentation, gasification/catalytic, pyrolysis/catalytic, aqueous phase, other), name of process, as relevant.
- Intended co-products, byproducts, and derivative(s)
- Any other information deemed by Nexant to be important

Nexant analyzed and provided an informed opinion on the accuracy and credibility of the information expressed, and used this analysis to derive a growth rate for the renewable chemicals sector. The study was completed in January 2012 and is available immediately at US$18,000 (eighteen thousand U.S. dollars).

Section 4 Methodology

The inventory of projects and capacities that are at the core of this report are based on Nexant's in-house knowledge and information, gained through numerous relevant engagements and analyses performed over the last two to four years. This in-house knowledge was supplemented by extensive review of public sources such as press releases, reports in the trade press based on interviews with company management and other stakeholders and experts, government loan applications and grants, U.S. SEC, and other government filings, construction permit applications, company annual reports, company websites, U.S. DOE and USDA surveys and reports, and reports of international bank sector analysts. Nexant has executed a large number of other similar surveys of this sector and of specific processes, products, and value chains, as well as single client feasibility studies for private industry and government agencies, and financial due diligence assignments on projects and technology platforms under development. This experience includes biofuels technologies that are very similar to those being proposed for some renewable chemicals, or are linked to them in "biorefineries", or supply them with feedstock (such as fuel ethanol feeding green ethylene production). Nexant leveraged this experience, in-house analyses and non-confidential information as a basis for this study. Nexant's experience and interviews with the companies and other stakeholders and experts was used to arrive at judgments of the credibility of the announcements.

In this report, Nexant evaluated the role of market partnerships between conventional chemical manufacturers and/or end users with renewable chemicals developers. Also considered were supply partnerships and/or sponsorship of feedstock suppliers, such as large agricultural or forestry industry players.

Government sponsorship, investments by venture capitalists and private equity players are also important, partly because due diligence has been applied by these entities to decide on their participation in developments and projects.

Comparisons and evaluations of the renewable products with conventional products being replaced, whether they are drop-in substitutes for the incumbents, or are entirely new molecules, are also relevant to the judgments of credibility. These are based on Nexant's in-house information regarding conventional process technology and markets, augmented by contacts with companies, the press, trade and technical associations, and other experts and stakeholders in the industry, and particularly with distributors, customers in the value chains, end-users such as the major packaging companies, OEMs and their trade associations. Commercial information and forecasts were developed from Nexant's extensive in-house databases, augmented with selected regional fieldwork.

While this study deals only with the first new, bio-based steps in chemical value chains, Nexant's market projections for conventional fossil-based organic chemicals were developed using Nexant's proprietary supply/demand modeling systems, such as Nexant's *ChemSystems* Simulator.

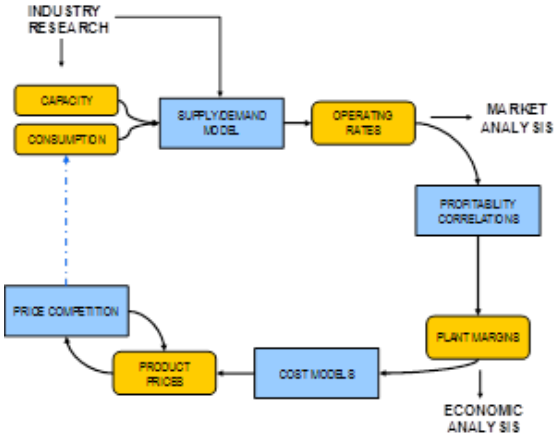
Nexant's *ChemSystems* Simulator is the proprietary simulation model developed by Nexant and used to generate all the analysis and forecasts of *ChemSystems* Online® and other offerings,

including Nexant's *ChemSystems* Petroleum and Petrochemical Economics (PPE) Program. The simulation model is an experience-based database running commodity petrochemical business logic algorithms to produce multi-scenario simulations of the global industry.

The integrated *ChemSystems* Online® Simulator simultaneously develops forecasts of regional consumption, production, imports, exports and inventory changes for all commodity petrochemicals in all countries/regions.

Nexant's *ChemSystems* Simulator delivers step change improvements in market forecasting and business/corporate planning, while reducing the resources and time required to evaluate multiple hypotheses and scenarios.

Figure 4.1 *ChemSystems* Simulator Simplified Logic Diagram



It is integrated from end-use markets back to petrochemical feedstocks. It considers inter-material competition, inter-regional price relationships, chain margins, product substitution, logistic costs and trade drivers. Costs and prices are integrated from crude oil, natural gas and petrochemical feedstocks through intermediate products such as MEG to downstream products such as PET bottle and textile resin made from them.

Section 5 Nexant's Experience

5.1 BACKGROUND

Nexant was established on January 1, 2000 and prior to that date, the staff of Nexant operated as a separate consulting group within a major engineering company. Nexant is now an independent company owned by a number of investors. Nexant acquired ChemSystems, Inc. on September 1, 2001, and the combined entity ("**Nexant**") now has access to even more enriched and extensive experience and resources, offering services that include:

- Master planning/feasibility studies
- Technology evaluation
- Techno-economic and commercial analyses
- Financial evaluation (cashflow modeling, etc.)
- Benchmarking
- Monitoring project implementation

Nexant is very well qualified to undertake the technical, commercial, economic and financial evaluations, from its own offices, without the need to subcontract. Owing to its extensive experience, and known for its "out-of-the-box" thinking, Nexant's *ChemSystems* Group has also received the honorable award of "Best Large Consultancy" by the British Consultants and Construction Bureau. This award was contended by a number of companies. However, Nexant was judged the winner for its outstanding contribution in developing a real-time, on-line chemical industry simulator.

5.2 DESCRIPTION OF SERVICES

Nexant's *ChemSystems* Group is now a part of Nexant's Energy and Chemical Consulting (E&CC) Division. Nexant is a specialist, not a generalist company. Our area of expertise is the energy and process industries, including oil refining, natural gas, petrochemicals, polymers, chemicals, pharmaceuticals and fertilizers. Our business has been built upon providing broad management consultancy services to leading companies active in these industries, and also to banks, suppliers, governments and others interested in these sectors.

Nexant's strengths lie in its combination of technoeconomic, commercial and strategic capabilities. These "competencies" are described below, followed by an outline of the practice areas into which the E&CC division is organized.

5.2.1 Technology/Economics

From its foundation in chemical engineering and industrial chemistry, Nexant offers distinctive expertise in process technology and economic analysis. Assignments may be performed on a separate, stand-alone basis or as input to broader consulting engagements.

Services include:

- Economic and financial analyses of projects or businesses
- Valuation of assets or businesses
- Technical audit of existing facilities
- Project feasibility/planning
- Technology innovation and assessment
- Comparative/competitive technology audit and appraisal
- Process design and cost estimation
- Technology availability, screening, licensing arrangements
- Contractor pre-qualification, evaluation and selection
- Project management, including resident advisory services
- Price, margin and profitability forecasting

This discipline is supported by comprehensive economics, cost and price databases.

5.2.2 Commercial

Based upon a technical and commercial understanding of the industries we serve, Nexant supports clients through a variety of market and commercial activities. As with our technoeconomic work, these commercial assignments may be performed on a stand-alone basis but are more normally an input to broader consulting engagements.

Services include:

- Feedstock and product market analysis
- Marketing and market research
- Supply/demand analysis and forecasting
- Studies of trends and future markets
- "Benchmarking" of costs and competitiveness
- Medium- and long-range planning

The commercial discipline is supported by databases of global supply, demand and capacity developments in all major petrochemicals.

5.2.2.1 Strategic Planning

Industry specific expertise and an understanding of world market forces distinguish Nexant's work in Strategic Planning. Various innovative tools and methodologies tailored to the energy and process areas are used to challenge conventional thinking. Nexant extends its traditional project team approach to engaging clients directly in the Strategic Planning process. Interactive client consultant relationships promote consensus, a critical factor for successfully developing pragmatic, implementable solutions.

Services include:

- Definition of corporate and business visions
- Portfolio planning
- Entry strategy evaluation
- Diversification, acquisition, divestment studies
- Competitive analysis and business positioning
- Global competitiveness
- Trade flow and impact studies
- Strategic options, selection and implementation

5.3 ASSIGNMENTS UNDERTAKEN WHICH COVER BIO-CHEMICALS AND FUELS

5.3.1 Multiclient Work

During the past five years, Nexant's E&CC division has completed a number of major multi-subscriber studies. Selected studies which included coverage of biofuels include:

- **Ethanol** -Analysis of fuel ethanol production by dry corn milling fermentation.
- **Biodiesel** - Including production technologies (commercial and developmental) and economics, feedstock issues, regulatory and market drivers, supply, and demand.
- **Glycerine** - Comparison of the natural oil and synthetic-based production routes - considering production technologies, economics, feedstocks, and global markets.
- **Methanol** - Nexant has done a number of Process Evaluation/Research Planning (PERP) reports, as well as other multi-client and single client reports on methanol and its derivatives.
- **Plants as Plants** – A study of the emerging biotechnology, processing technologies and economics of producing and recovering polyhydroxyalkanoates (PHAs) - natural polyesters – by alternative routes of fermentation and in crops, including analyses of agricultural production economics, PHA extraction costs, byproduct biomass fuel utilization, and potential PHA markets.
- **Biotransformation Routes to Specialty Chemicals** – Includes consideration of conversions of natural oils, fatty acids, fatty acid esters, fatty alcohols and fatty amines,

and fermentation technologies and commercial overviews of many bio-based product markets.

- **Refinery of the Future as Shaped by Environmental Regulations** – Reviews issues of supply and quality of crude oil feeds to refineries, trends in quality and volume requirements for refined products, and environmental drivers for both refinery operations as well as fuel specifications.
- **Biodesulfurization of Petroleum Fractions** – Compares various versions of conventional refinery hydrodesulfurization with developments in fermentation based biodesulfurization.

Nexant's E&CC division has also completed a number of definitive studies on specific regions. These studies have analyzed the business structure and opportunities for many of the chemicals covered in this proposed study within the context of a changing economic environment. In addition to these studies, Nexant's E&CC division maintains a global commercial and technoeconomic database covering the principal petrochemicals, intermediates and polymers.

5.3.2 Single Client Studies

- **Global Biofuels Strategy** - For a leading U.S.-based multinational firm grounded in the agricultural sectors, Nexant performed a comprehensive analysis comparing technological, supply chain, and geographic options for involvement in the biofuels sector.
- **Technology, Company, Finance, and Project Due Diligence in Biofuels** – Nexant has performed a number of recent due diligence assignments for financial institutions assessing the feasibility and value of technologies, companies, businesses, or proposed projects focused on bioethanol or biodiesel.
- **Chemicals from Corn** - This was a broad-based study for the National Corn Growers Association (NCGA), funded by the U.S. DOE, to identify and screen chemicals that could be feasibly produced from corn. The study considered a wide range of potential sugars, and fermentation-derived acids, alcohols, and other building blocks, but emphasized fuel ethanol derivatives, including basic petrochemicals, solvents, intermediates and specialties, and application of the Reactive Distillation technology sponsored by the NCGA. The basic economics of ethanol production and potential improvements, economies of scale, logistics, and other production and value chain issues, are addressed in the study.
- **Biodiesel Glycerine Byproduct** - Market Dynamics - For a major U.S.-based multi-national agricultural and food company with a growing stake in biofuels, Nexant analyzed the market demand/price elasticity (with a growing glut of biodiesel glycerine byproduct), existing uses of glycerine, potential substitutions for others polyols such as propylene glycol and sorbitol, and potential future applications, including reaction derivatives of glycerine in various applications and fuel uses. Nexant considered the near term and emerging and long-term market outlets for USP and other refined grades of glycerine, as well as for crude biodiesel glycerine byproduct, which is of a more

problematic quality than soap and oleochemical byproduct. The study required developing views of biodiesel growth, and pricing scenarios under various assumptions.

- **Biobased Fuel Cells** - At the BIO World Congress on Industrial Biotechnology and BioProcessing, Orlando, FL, April 20-22, 2005, Nexant presented a paper on biofuels use in fuel cells based on a study of Stationary Fuel Cells for Nexant's *ChemSystems* Process Evaluation/Research Planning (PERP) Program, and also chaired a panel on bio-based fuel cells, which included discussions of enzyme-based fuel cell membrane and electrode technologies to utilize hydrogen or biofuels.
- **Ethanol versus MTBE - Litigation Support** - Nexant advised the U.S. Department of State in an action defending California against methanol interests for claims of losses in the phase-out of MTBE and use of ethanol as a substitute gasoline oxygenate. This work included a detailed analysis of the ethanol production and distribution infrastructure in the United States and addressing practical, environmental, safety and issues of using ethanol in gasoline.
- **Ethanol Market and Cost Competitiveness Evaluation** - Nexant was retained by an ethanol producer and its financial advisor to provide an independent market study and evaluation of project cost competitiveness to help raise funds to convert an existing sugar- and corn-based ethanol plant in Louisiana to process organic waste (biomass) as a feedstock.
- **Biomass Ethanol Process Evaluation** - Nexant performed a detailed technical and economic analysis of a commercial scale plant for the production of fuel grade ethanol from wood biomass via fermentation, a process developed by a national energy laboratory. Among the goals of the program was the incorporation of the latest R&D developments into the design. The results from this study were compared against earlier designs.
- **Biomass Ethanol Development Technical Support** - Under a multi-year program, Nexant provided technical support for the SERI program to develop viable alcohol fuels production technology based on cellulosic feedstocks. Activities included: investigation of prototype cellulose to ethanol via hydrolysis plant designs for capacities of 50 million to 250 million gallons per year; detailed design and capital cost estimate for an anhydrous ethanol plant based on enzymatic hydrolysis of hardwood chips; techno-economic evaluation of proposed processes including biomethanation of biomass pyrolysis gases and liquid fuels from cellulosic biomass.
- **Ethanol Project Management** - A Midwestern U.S. ethanol producer of corn-based gasohol retained Nexant to assist in the implementation of its 40 million gallon per year project. This included a review of the process technology and hardware provided by technology licensors and vendors. Nexant's study assisted the client to obtain Federal loans and secure bank financing.
- **"Forest Refinery" Industry Evaluation** - A U.S. national laboratory retained Nexant to assess the technical and economic feasibility of a forest refinery designed to manufacture chemical products from trees. The analysis screened a variety of biomass conversion technologies and compared the production costs and energy consumption levels of each

route to conventional routes. Processes evaluated included fermentation, lignocellulose separation, lignin conversion and gasification.

- **Cellulosic Ethanol Feasibility Analysis** - A synfuels company retained Nexant to determine the technical and economic feasibility of using cellulosic feedstocks to produce commercial quantities of fuel grade ethanol. Alternative feedstocks (corn and other grains) and byproducts were included in the evaluation.
- **Enzyme Process Assessment** - Nexant assessed the impact on process economics and energy consumption resulting from substituting immobilized cells of *Zymomonas Mobilis* for conventional yeast in a commercial corn-based ethanol facility.
- **Fuel Ethanol Opportunity Analysis** - A major oil/chemical company interested in developing fuel grade ethanol facilities in the Midwest retained Nexant to assess the competitive aspects of ethanol/gasohol. Factors evaluated included state incentive programs and change prospects, freight costs to prospective markets, and the current level of penetration of unleaded gas by ethanol.
- **European Ethanol Markets Analysis** - A study for a Japanese client reviewed the West European ethanol business, including synthetic and fermentation sources. Demand, pricing, grades, end-uses, ethanol production by location and production economics were provided. In another study for this client, Nexant compared the economics of the four plants producing synthetic ethanol with the most efficient (molasses) fermentation ethanol producer.
- **Ethanol Drying** - For a Japanese client, Nexant reviewed the methods used in Western Europe to dry ethanol (including fermentation sources), discussed the merits of newer technologies, and investigated international legislative actions to restrict the use of benzene or cyclohexane in azeotropic distillation.
- **Ultra Clean Fuels Study** – For Conoco, under U.S. DOE sponsorship, Nexant performed a comprehensive review of the future for ultra low sulfur diesel (ULSD) and other petroleum distillates in transportation: considered regulatory and market drivers, production technology and economics, petroleum refining impacts, environmental/resource depletion impacts, vehicle engine and performance, consumer acceptance, distribution and refueling logistics, diesel and gasoline ICE operational issues, stationary combustors. For fuel cells: the objective was to determine the feasibility of using GTL fuels – Fischer-Tropsch distillate and naphtha and methanol (comparisons to hydrogen, ethanol and biodiesel included). At issue was the use of biodiesel as a lubricity additive to counter the reduced lubricity with loss of sulfur in ULSD and GTL.
- **Synthesis Gas (Future Sources)** - This report reviewed the technology for production of synthesis gas (H_2, CO mixtures) from a number of sources. Most emphasis was devoted to coal and biomass (municipal solid waste and wood) gasification and new gasification technology. The report discussed downstream processing requirements and examined coal and biomass properties and their impact upon gasifier design. The economics of producing industrial fuel gas (gasifier effluent after acid gas removal) via different routes were compared to the direct use of natural gas and low sulfur fuel oil.

- **LNG Competition with Clean Diesel** – For a multinational industrial gas company with a stake in technology for LNG as an alternative vehicle fuel/CNG refueling strategy, Nexant studied the current status of "clean diesel" (e.g., engine modifications along with ultra low sulfur diesel fuel enabling use of particulate traps and catalytic tailpipe controls to reduce soot and NOx emissions), and assessed the competitiveness of biodiesel in this context.
- **Global Finished Automotive Lubricants Market Drivers** – For a leading U.S.-based multinational lubricants additives maker, Nexant studied the current and projected global market dynamics for finished automotive lubricants for the next two decades. Market segments/products included passenger car and diesel/heavy-duty crankcase, gear oil, automatic transmission, tractor, off-road and small engine lubricants. Fleet growth in various regions, ultra low sulfur diesel, and trends to "dieselization" of fleets in various regions were relevant issues examined. In this and other related work, Nexant has opined that a key vector for use of biodiesel, aside from as a fuel per se, will be as a lubricity additive to ultra low sulfur diesel. Also key will be demand for biodegradable, non-toxic biodiesel fuel in small boats in place of other marine fuels.
- **Synthetic-Based Drilling Fluids (SBFs)** – For a multinational specialty chemicals company with a stake in oleochemicals and GTL, Nexant studied market issues and projected markets for SBFs in deepwater drilling, as driven by recent U.S. EPA regulations or these oil-based systems with respect to disposal of drilling spoils (especially in the Gulf of Mexico, but in other seas as well). The only systems allowed, by consensus in a stakeholders-involved regulatory development process, are those based on Internal Olefins (IOs) and vegetable esters (essentially, "biodiesel"). These alternatives strike a balance in meeting both toxicity and biodegradability limits.
- **Biodigestion of Food Wastes** – Nexant performed technology audits and market studies for MOM-ECAP, and another, Kuwait-based developer of projects in New York City, New Jersey and Kuwait to ferment food wastes to produce liquid and solid fertilizer/fungal disease suppressant products by the (aerobic) EATAD process of IBRC of Vancouver, BC. This also included analyses of competitive anaerobic based biodigestion technologies.
- **M2M Feasibility for Developing Economies** – For USAID, Nexant studied the feasibility of capturing various streams of fugitive methane and bringing them to market ("methane-to-market", or M2M), including anaerobic biodigestion of agricultural waste biomass.
- **Fatty Alcohols from Coconut Oil Project – (Cebu, The Philippines)** – This was an extensive technical and market due diligence for a bank on the client's proposed new fatty acids/fatty alcohols plant, which involved visiting the client on Cebu, and a number of experts and oleochemicals sites in the Philippines, meetings with the process technology vendor, Lurgi AG, in Cebu and in Frankfort, Germany to review technology, flowsheets, and project budget, and performing a competitive market study (Asia and

global supply/demand, prices, competition, etc.). The study included consideration of byproduct glycerine purification and disposition.

- **Oleochemicals Feasibility Study** - For London-Sumatra's proposed new production in Indonesia, Nexant surveyed the global oleochemicals industry and markets, focusing on palm and palm kernel oils, glycerine, fatty acids, and fatty esters compared to other natural oil-based products and competition with food markets.
- **Surveys of Global Oleochemicals Markets and Technologies** – Nexant addressed natural and synthetic-based oleochemicals markets for a major chemical company.

Section 6 Contact Details and Subscription Information

6.1 CONTACT DETAILS

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6.2 AUTHORIZATION FORM, TERMS AND CONDITIONS

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